Public

Status and outlook of LPP light sources for HVM EUVL

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Outline

- NXE3300 and NXE3350B progress and status
  - Roadmap, Layout, Performance
- EUV source architecture and performance
- EUV source power scaling beyond 100W
  - EUV LPP technologies
  - Pre-pulse technology
  - EUV source Drive laser
  - Droplet generator
  - Collector: protection, lifetime
- Summary

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EUV technology roadmap, source architecture and performance

NXE technology roadmap

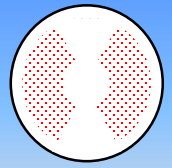
Extend NA 0.33 to below 10nm

Improved lens and illuminator performance

Imaging / Overlay performance match node requirements

Increased throughput at increasing doses

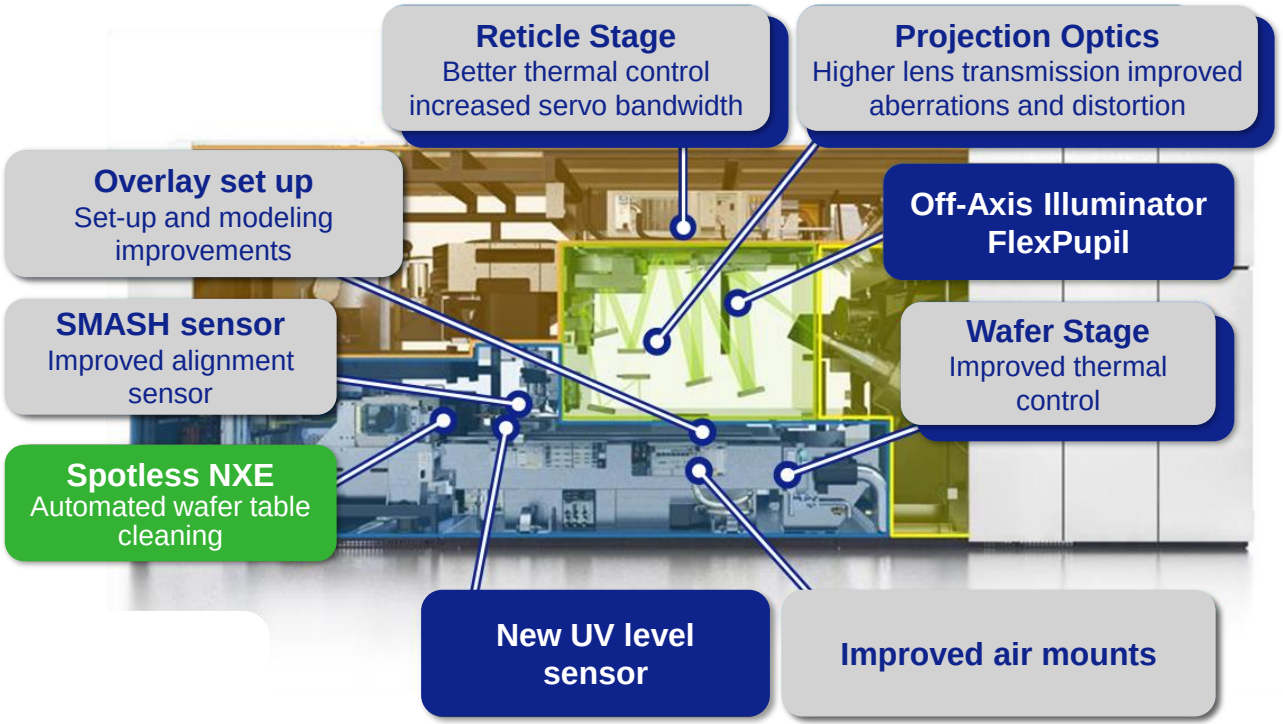
						Under study			
Resolution [nm]		**32**	**27**	**22**	**16**	**13**	**10**	**7**	**<7**
Wavelength [nm]		13.5							
Lens	NA	0.25		0.33			0.33NA DPT		
								>0.5NA	
	flare	8%		6%	4%				
Illumination	coherence	σ=0.5	σ=0.8	σ=0.2-0.9	Flex-OAI	Extended Flex-OAI			
						reduced pupil fill ratio			
Imaging	CDU [nm]	-	2.0	1.7	1.3	1.1	1.0	0.9	
Overlay	DCO [nm]	7	4.0	3.0	1.5	1.4	1.2	1.0	
	MMO [nm]	-	7.0	5.0	2.5	2.0	1.7	1.4	
TPT (300mm)	Dose [mJ/cm^2]	5	10	15	20	20	20		
	Power [W]	3	10 - 105	80 - 250	250	250	500		
	Throughput [W/hr]	-	6 - 60	50 - 125	125	125	165		



pupil fill ratio defined as the bright fraction of the pupil

NXE:3350B: 2x overlay improvement at 16nm resolution

Supporting 7nm logic, ~15nm DRAM requirements



Resolution	16nm
Full wafer CDU	≤ 1.3nm
DCO	≤ 1.5nm
MMO	≤ 2.5nm
Focus control	≤ 70nm
Productivity	≥ 125 WPH

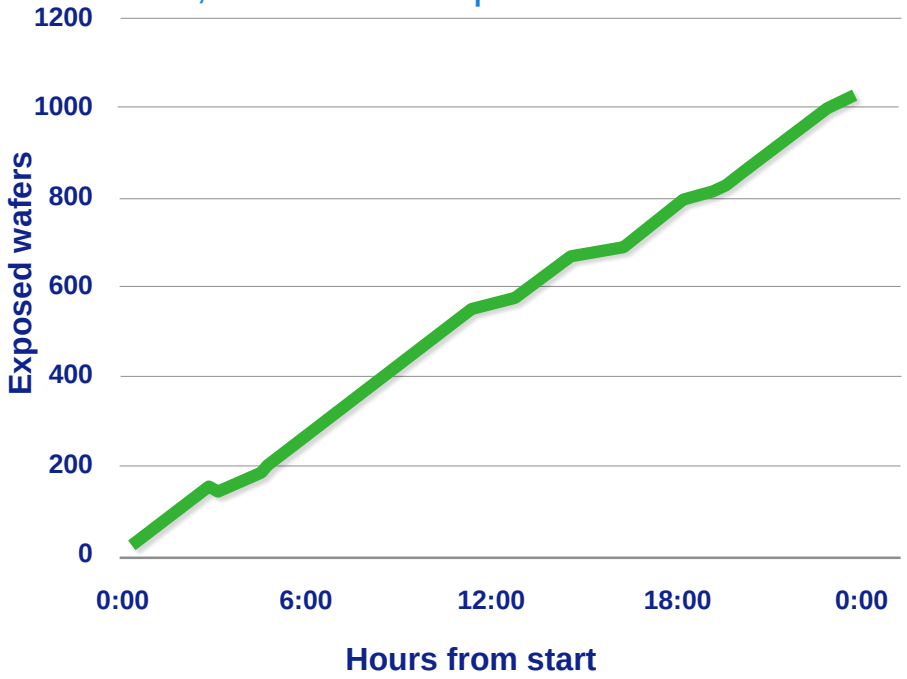
Overlay
Imaging/Focus
Productivity

1000 wafers per day capability demonstrated

On a field system, using customer exposure conditions

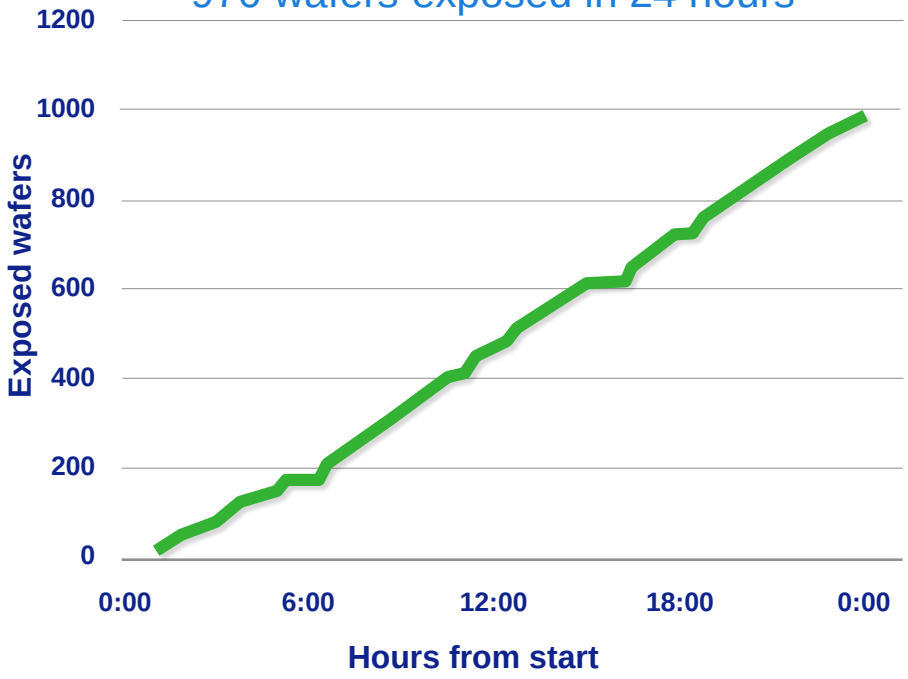
January 22, 2015:

1,022 wafers exposed in 24 hours

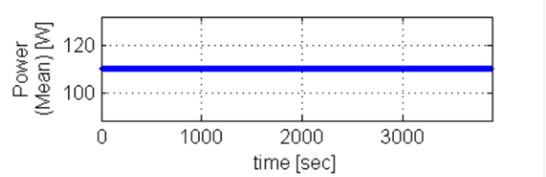


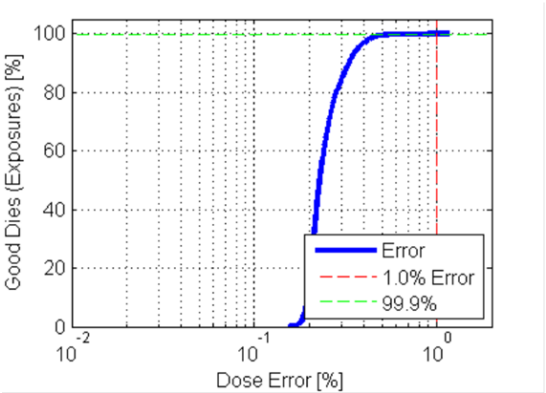
February 8, 2015:

970 wafers exposed in 24 hours



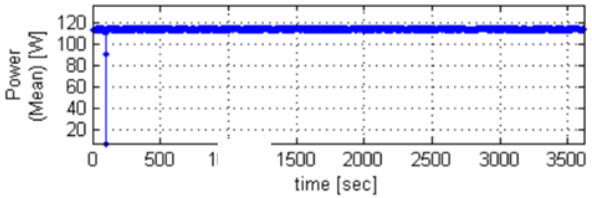
Multiple UP2 systems delivering >100W EUV power

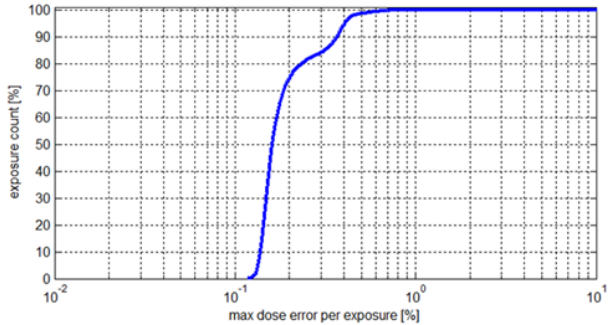




Pilot 6

110W, 1 hour run

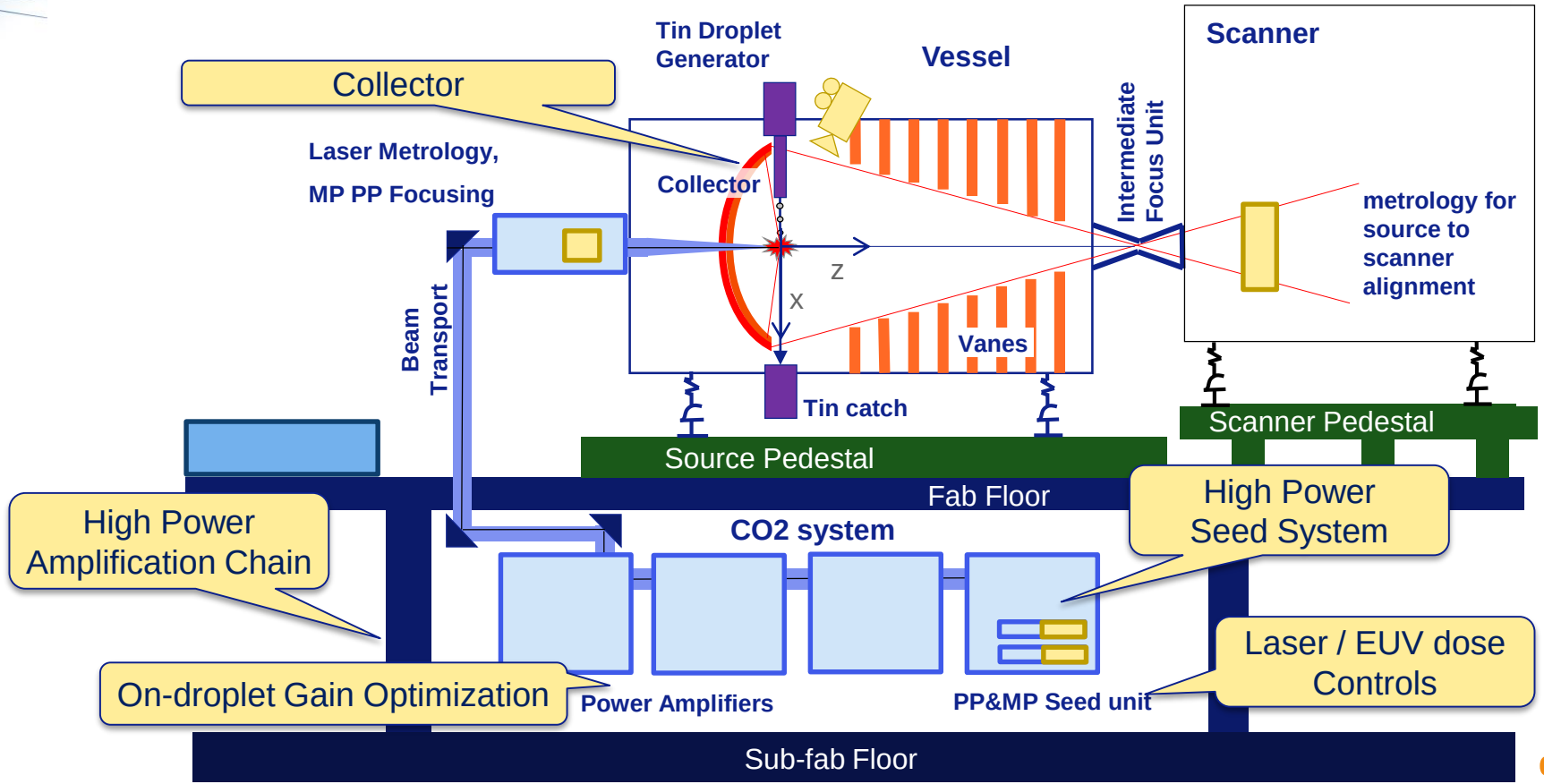




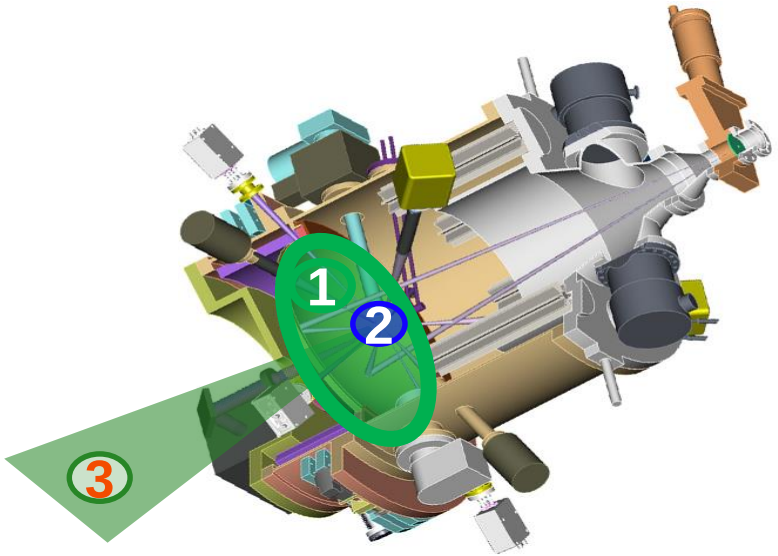
Cymer 2

~110W, 1 hour run

EUV Source Architecture, Sn LPP MOPA PP



EUV LPP Source Key Technologies



Optics Protection 1
(Debris Management)
- Collector protection by gas flow
- In-situ collector cleaning
- Collector capping layers

Availability / CoO

Targeting Dynamics 2
- Target conditioning
- Focus Control
- x,y,z, E & t control

Dose Control / Yield

CO_2 Laser Power 3
- High power drive laser

Conversion Efficiency
- Prepulse

EUV Power / Throughput

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EUV source power scaling beyond 100W

Source power and availability drive productivity

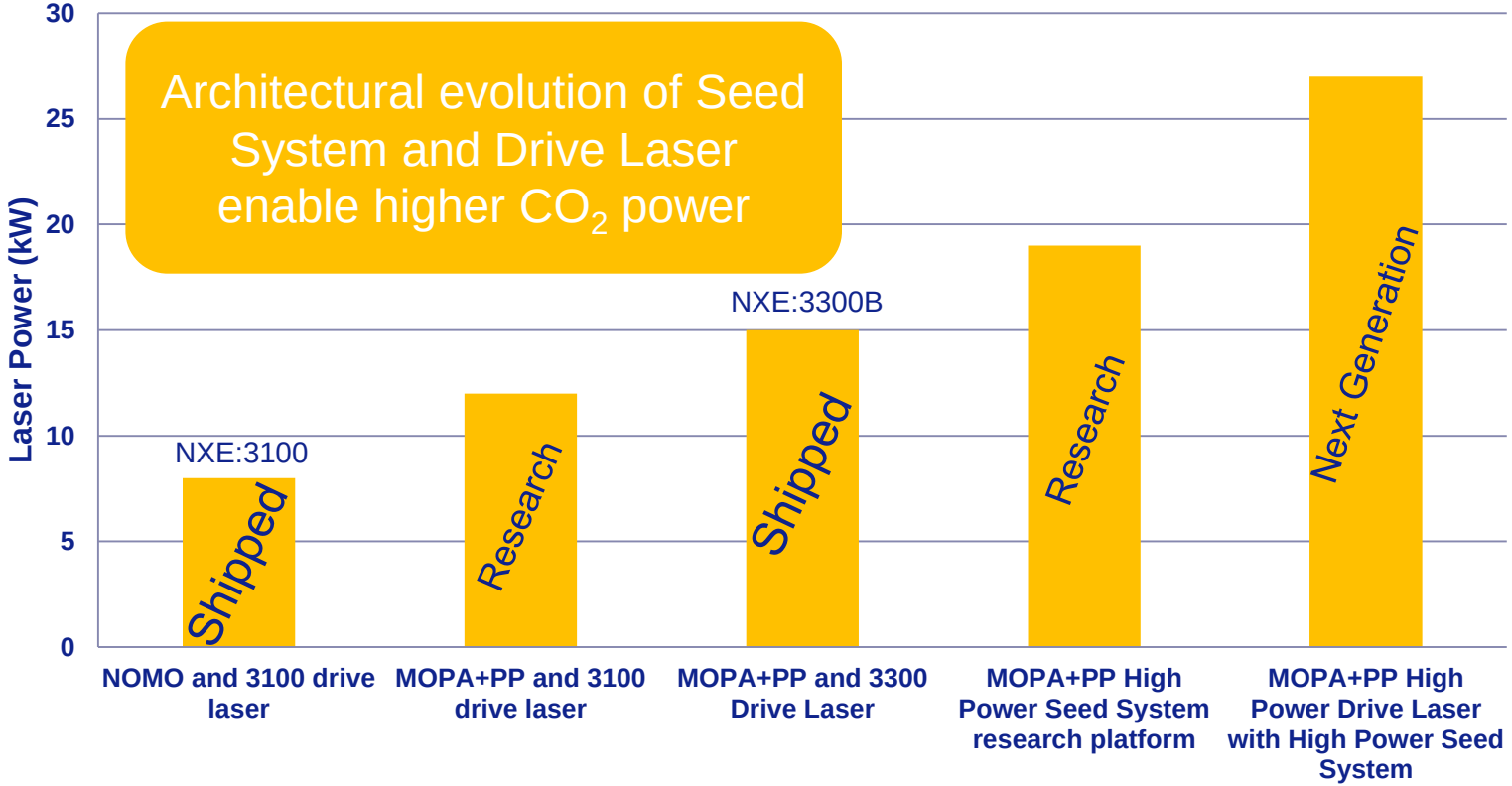
Technology development work is ongoing to improve all aspects

Source power	Drive laser power
	Conversion efficiency
	Dose margin
	Optical transmission
Source availability	Automation
	Collector protection
	Droplet generator reliability & lifetime
	Drive laser reliability

Introduction: EUV Power Scaling

EUV power at the intermediate focus (W) ∝

CO_2 power (W) * Conversion Efficiency (%) * (1-Dose Overhead (%))



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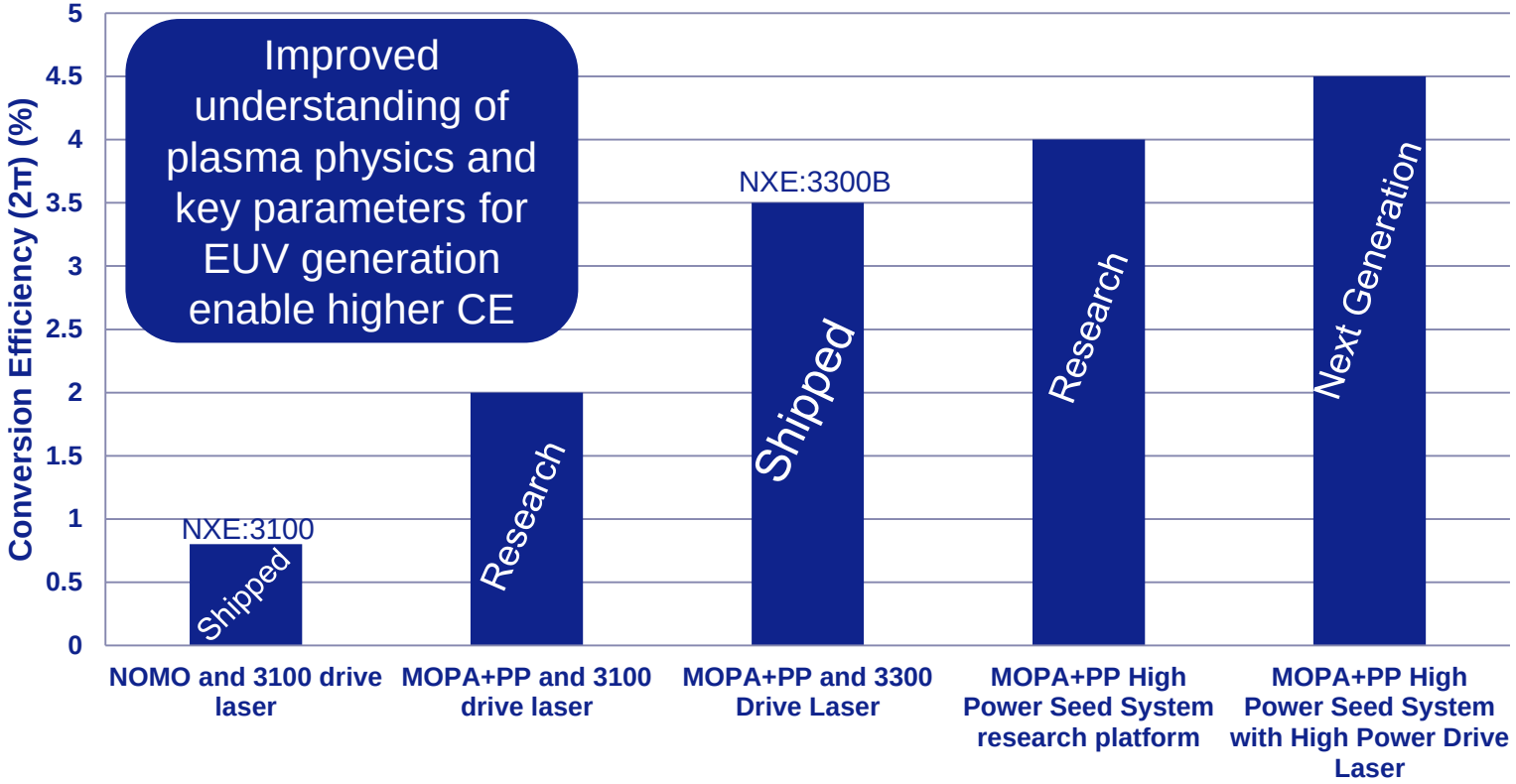

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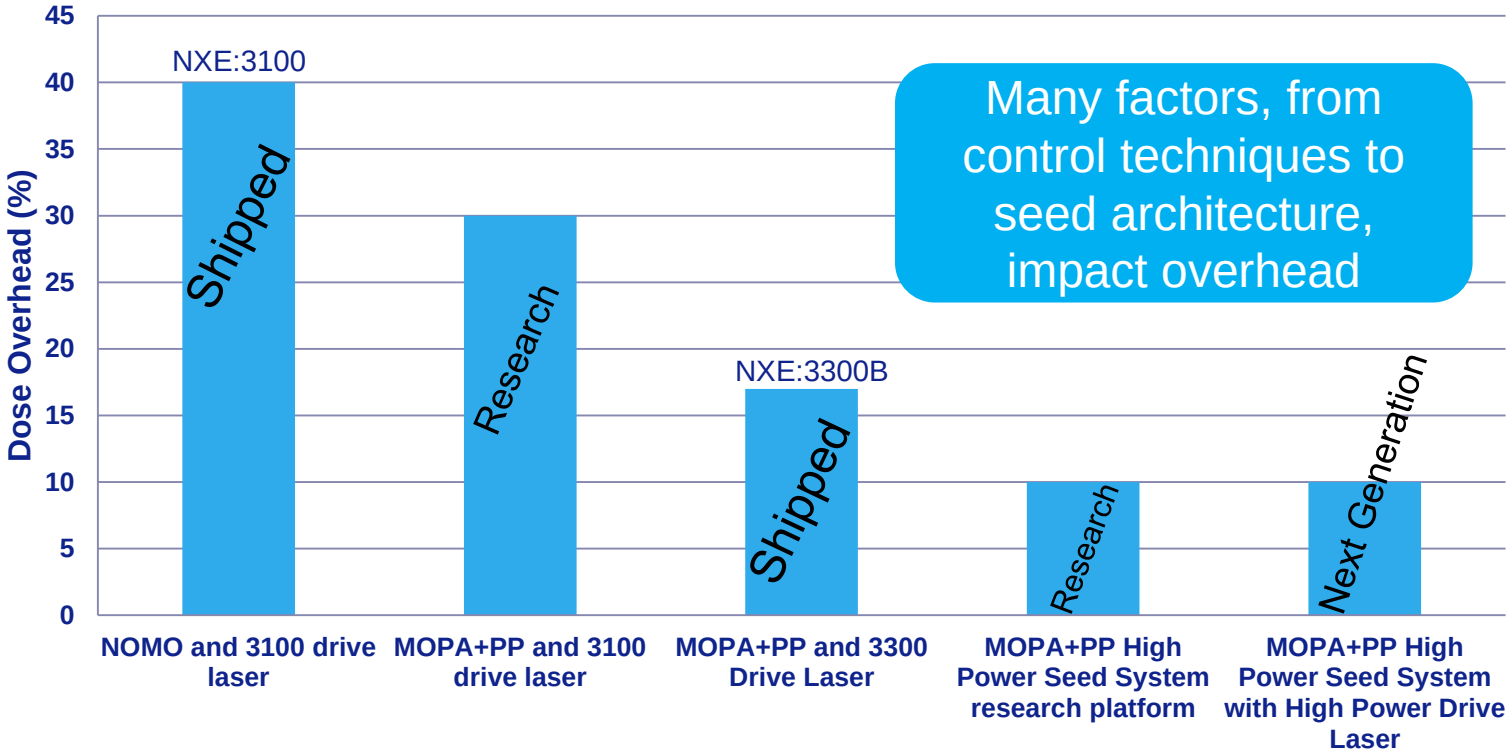
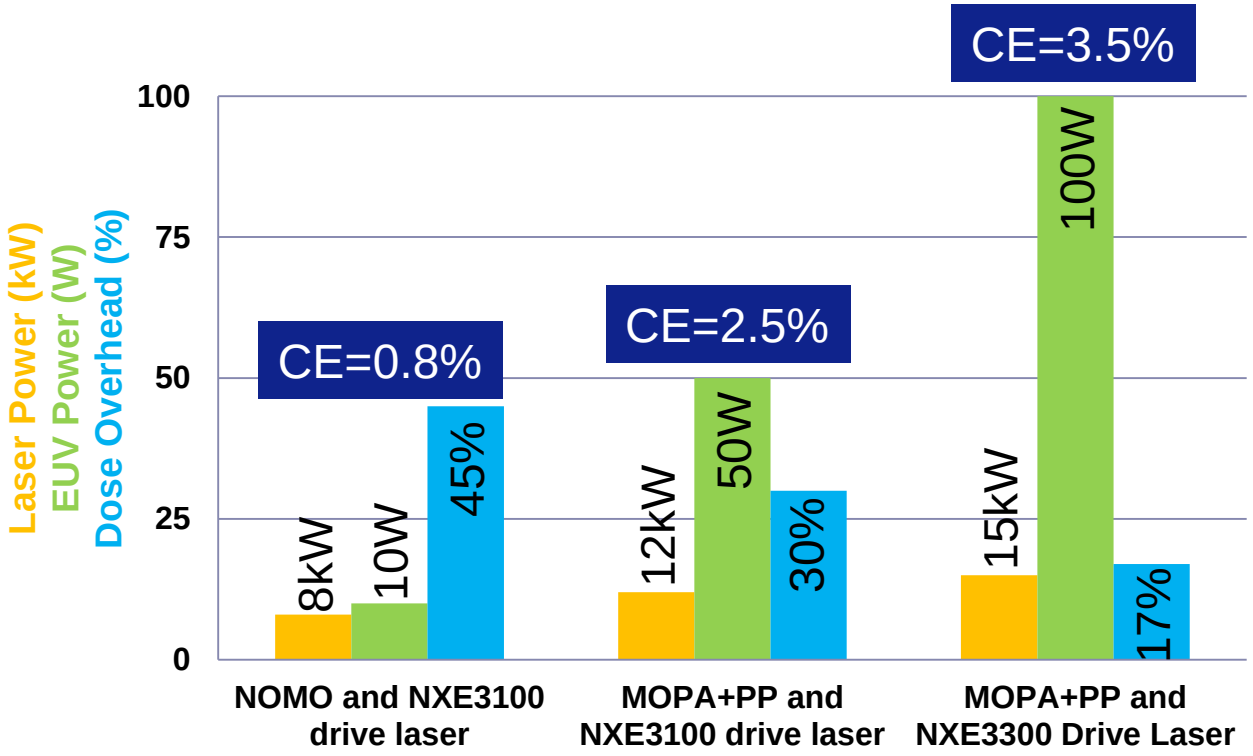


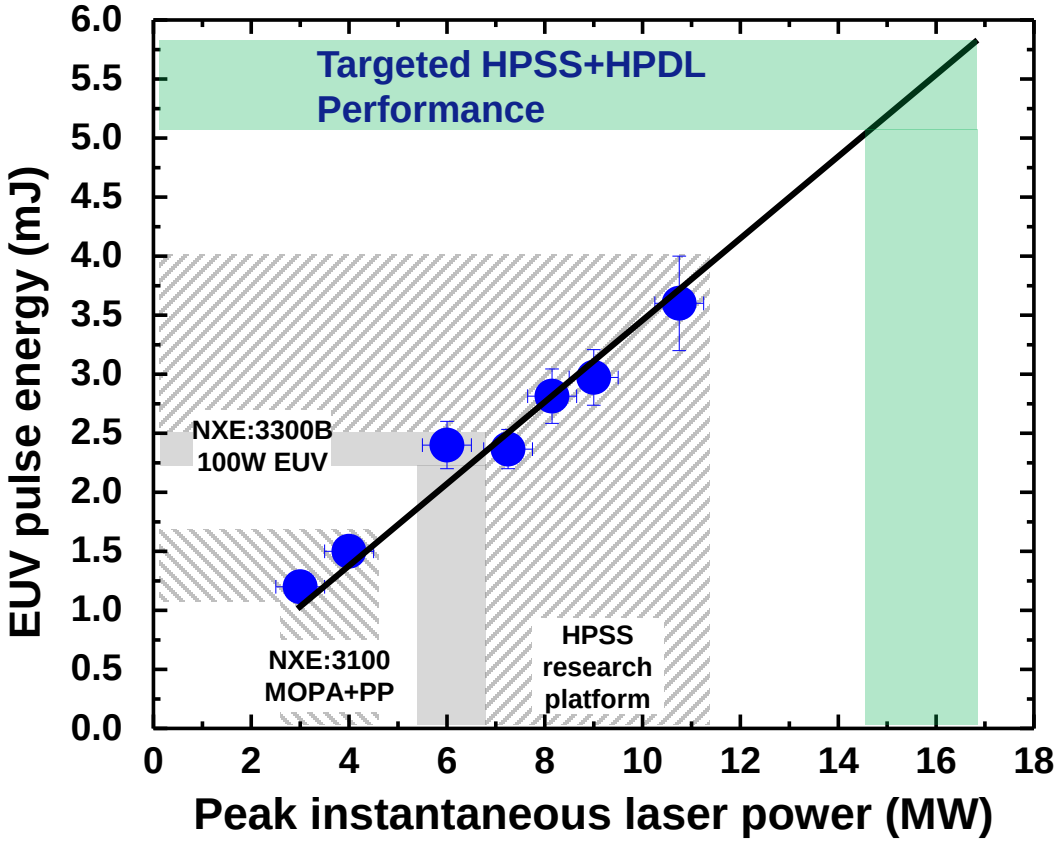
Recap of EUV power scaling through 2014

EUV power at the intermediate focus (W) ∝

CO_2 power (W) * Conversion Efficiency (%) * (1-Dose Overhead (%))



EUV Pulse Energy and Power



Current state

- 3.5% EUV CE
- 16kW on-droplet laser power
- 2 – 2.5mJ EUV pulse energy
- 80 – 100W dose controlled EUV power

Development platform

- 4% EUV CE
- 2.5-4mJ EUV pulse energy

Next performance level 250 W

- higher EUV CE
- Increased peak / average CO_2 power

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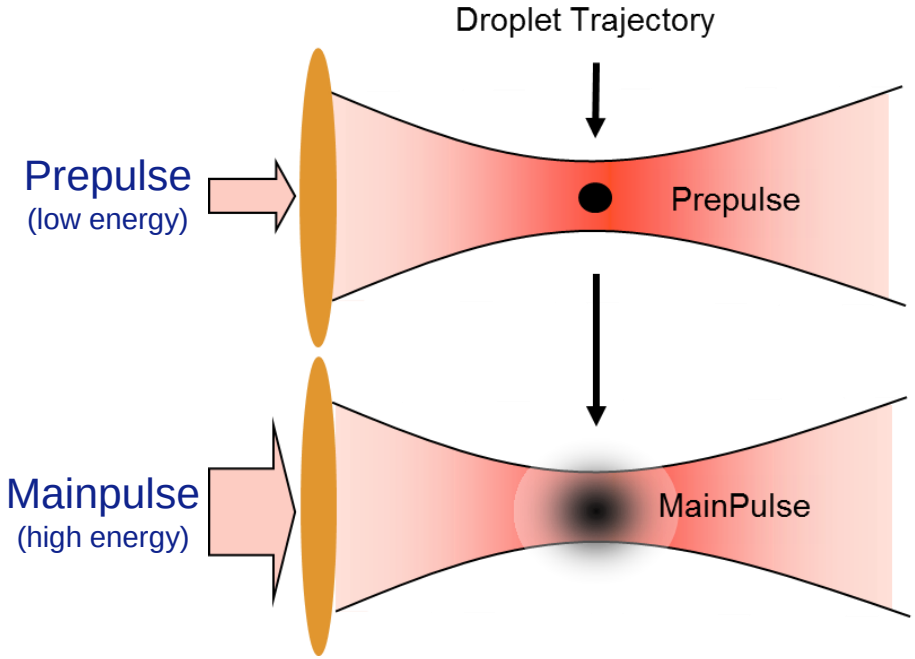
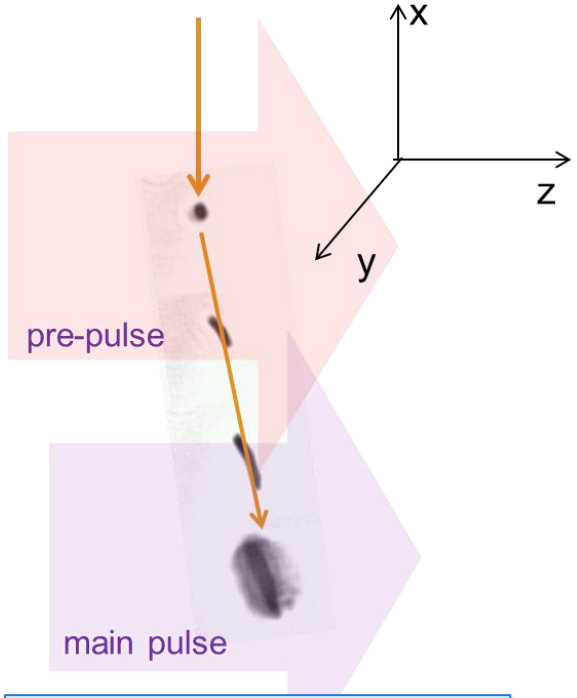
Pre-pulse technology

Conversion efficiency: Optimizing pre-pulse to create a more efficient target



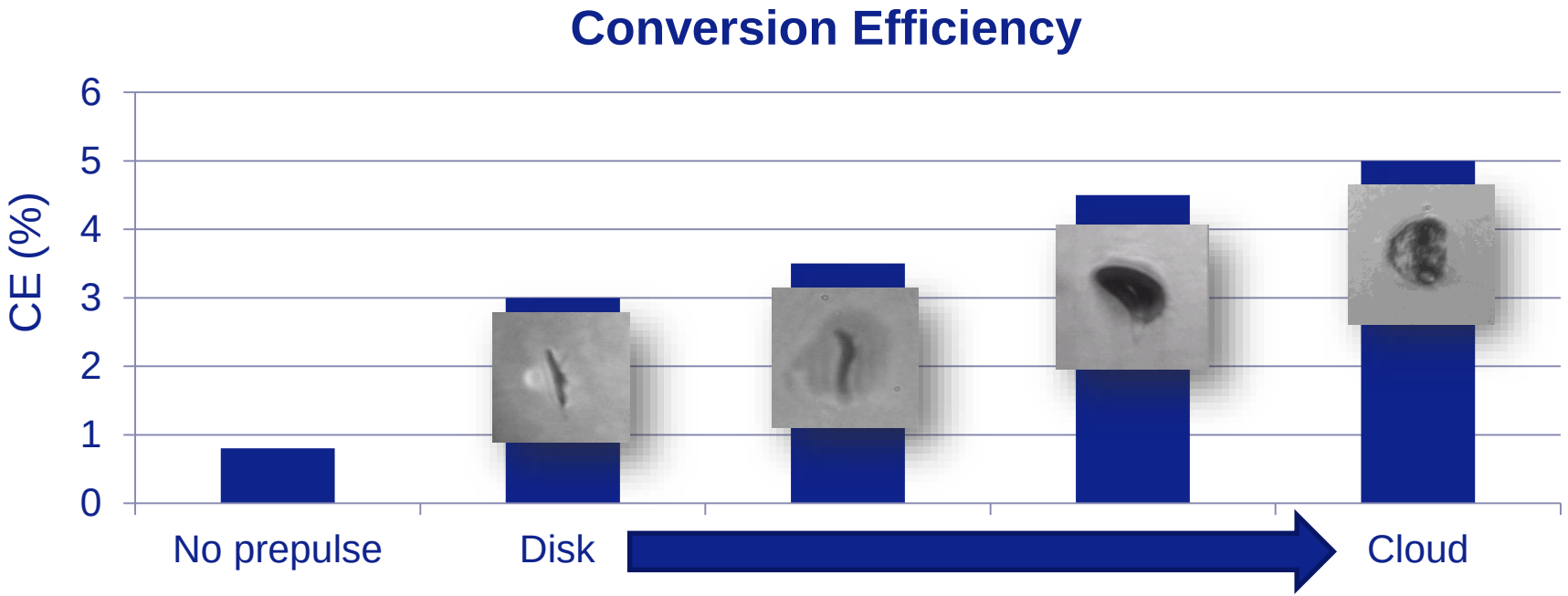
Target expansion fills main pulse beam waist



Target shape changes from droplet to disk

Increased conversion efficiency with Pre-pulse

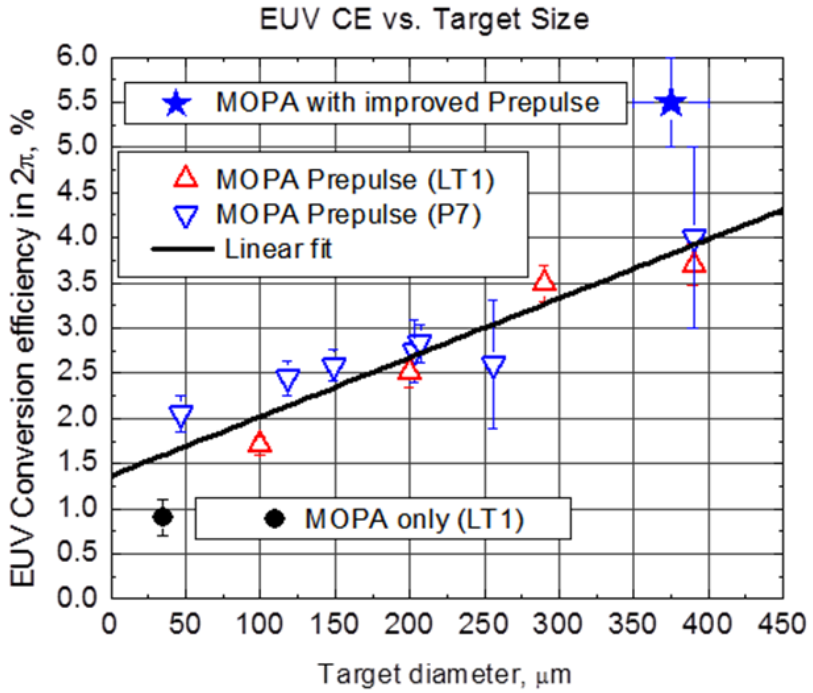
Enabled by optimized target shape and size



Examples of target formation capabilities utilizing various Pre-pulse techniques – CE >5% demonstrated on research platforms

Increased conversion efficiency with Pre-pulse

Enabled by optimized target shape and size



Pre-pulse enhances CE via reduced target density for better CO_2 absorption, increased EUV emitting volume, reduced EUV absorption

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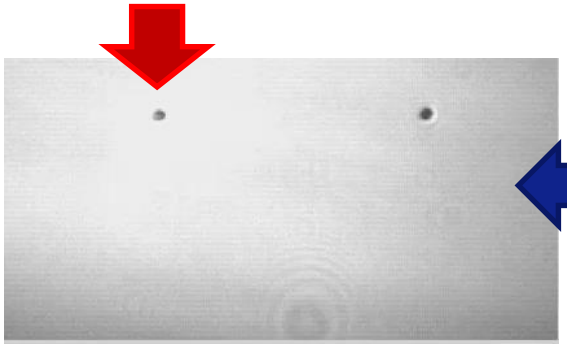
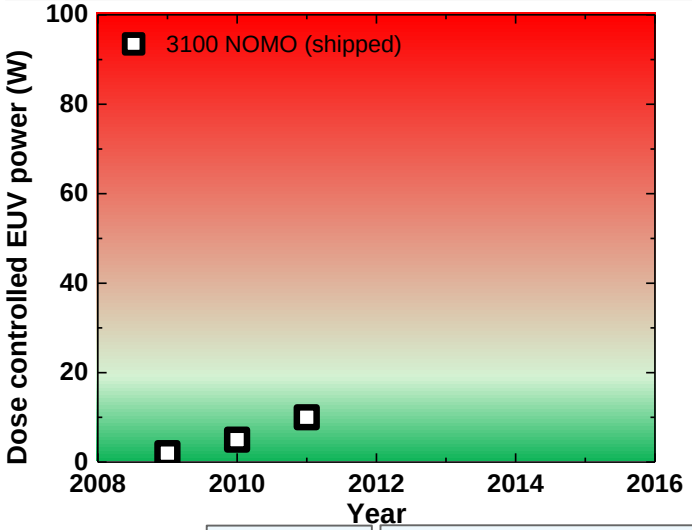
EUV Source, Drive Laser Development Progress

EUV source progress, NXE3100, NOMO

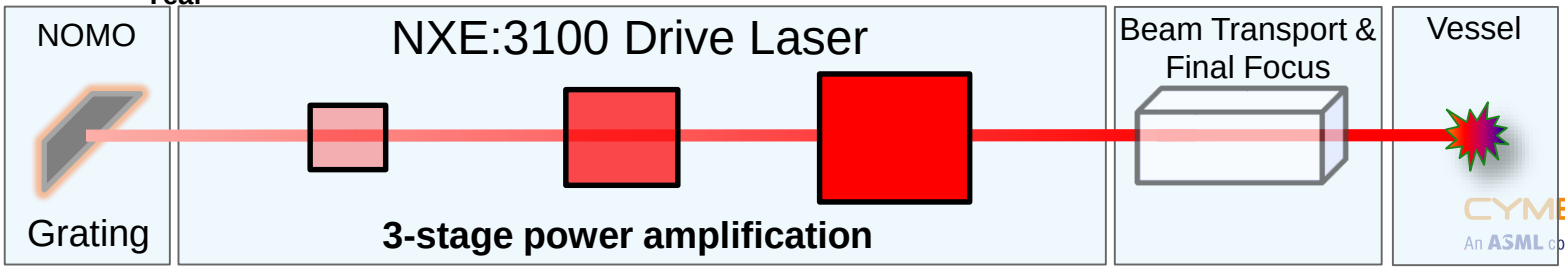
NXE:3100 NOMO Principle: Laser cavity forms between grating and droplet, making plasma





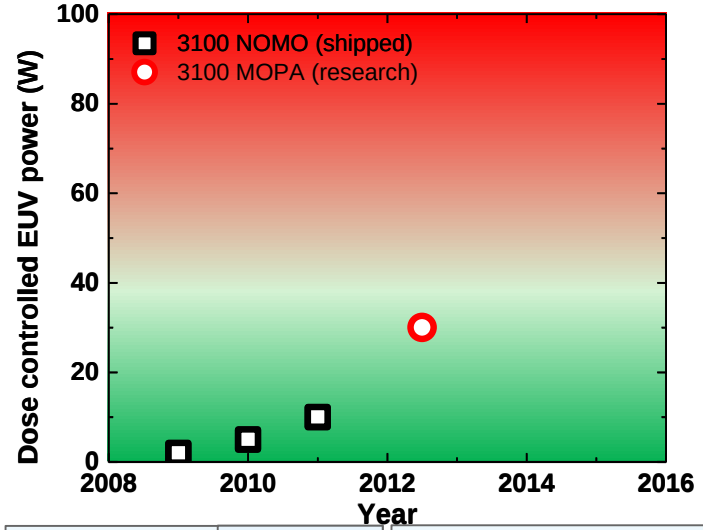
EUV power scaling with NXE:3100 NOMO architecture limited by:

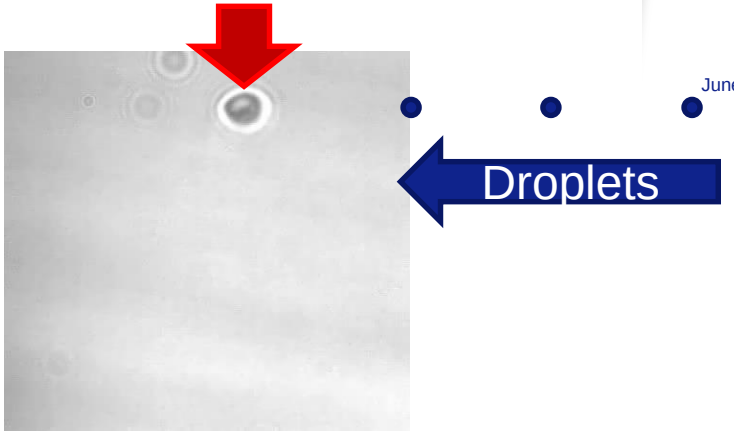
- low conversion efficiency (<1%)
- uncontrollable spontaneous emission for increased laser gain



EUV source progress, MOPA

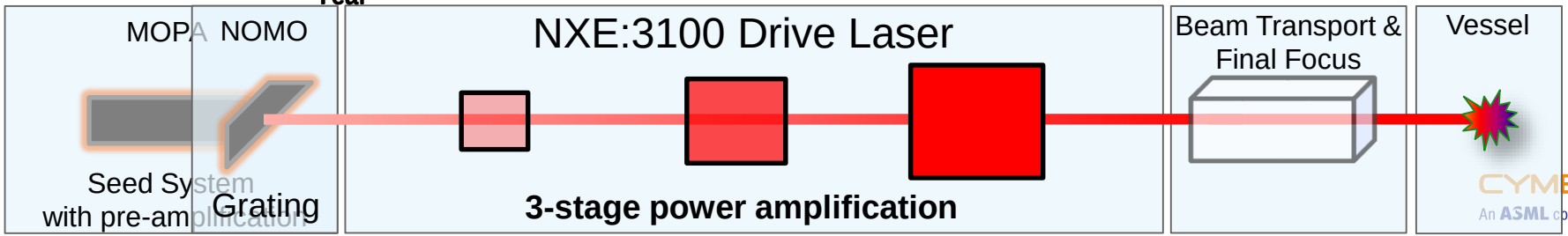
NXE:3100 MOPA Principle: Seeded laser amplifiers enable higher gain storage





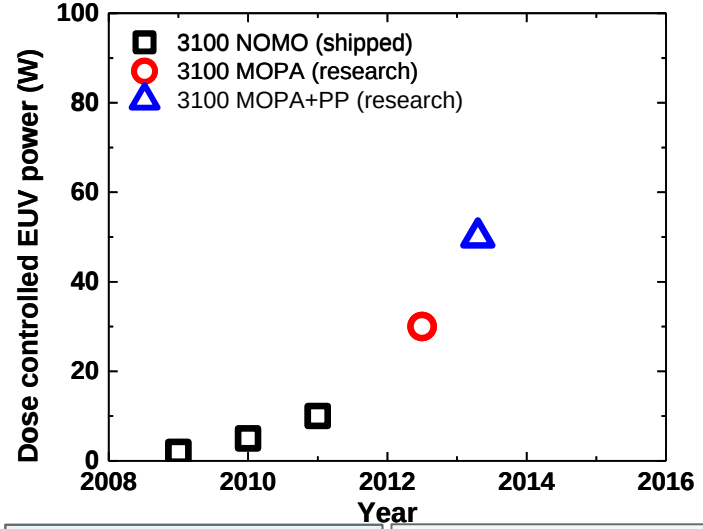
EUV power scaling with NXE:3100 MOPA architecture limited by:

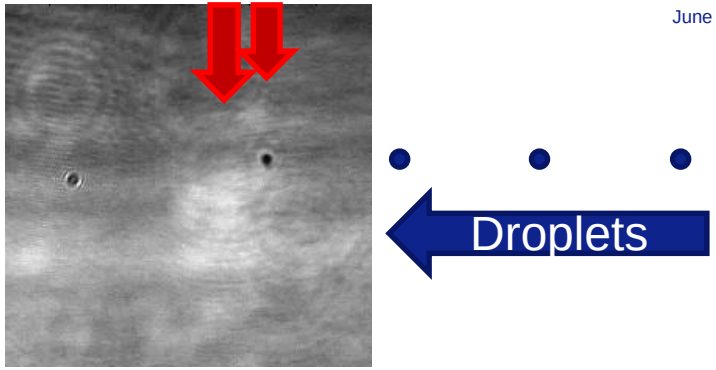
- relatively low conversion efficiency (<1.5%)
- excessive tin debris generation

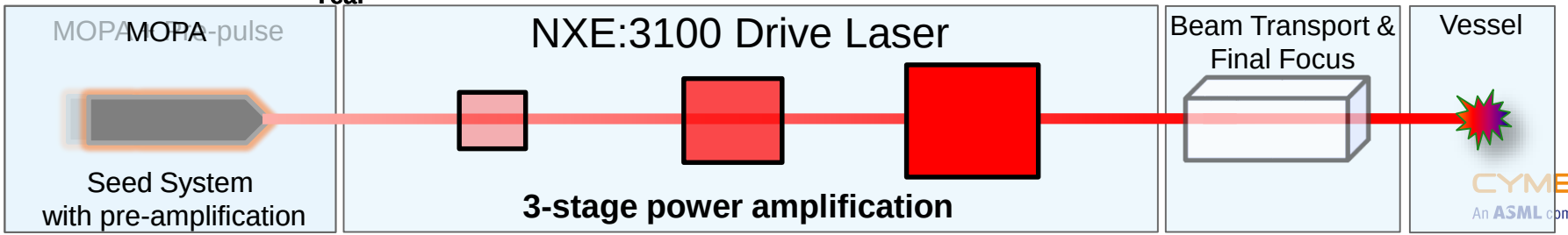


EUV source progress, MOPA Pre-Pulse

NXE:3100 MOPA Pre-pulse Principle: increased efficiency and reduced debris via precise target formation

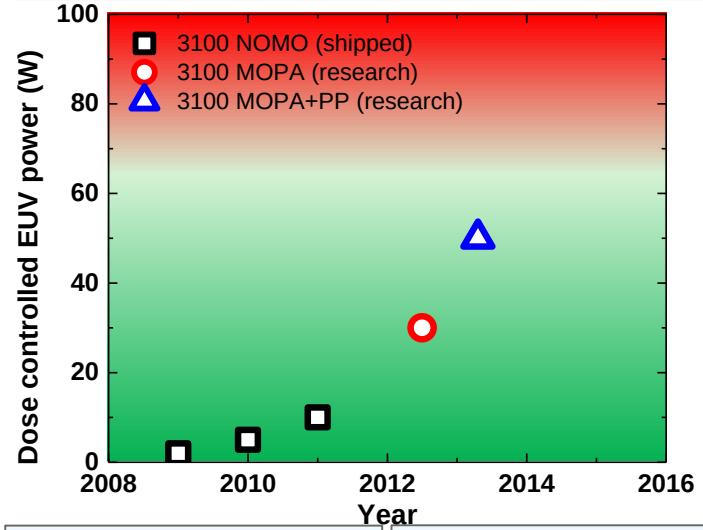


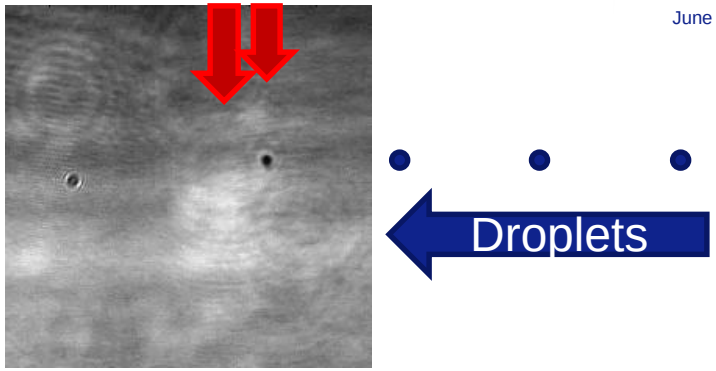




EUV source progress, MOPA Pre-Pulse

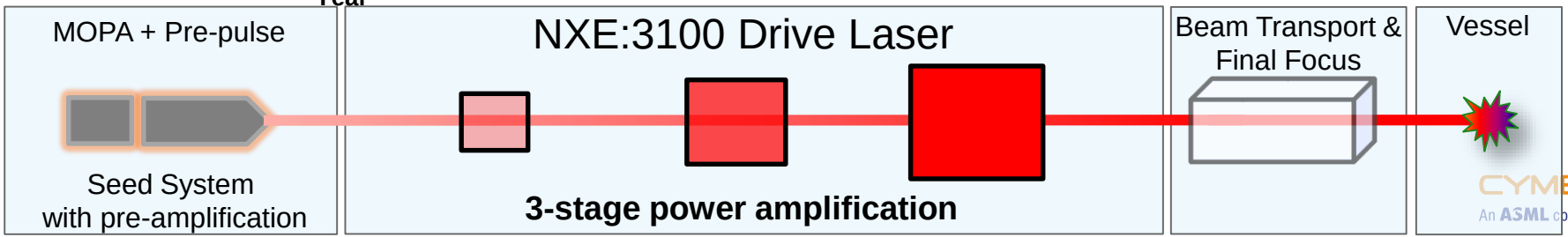
NXE:3100 MOPA Pre-pulse Principle: increased efficiency and reduced debris via precise target formation





EUV power scaling with NXE:3100 MOPA Pre-pulse architecture limited by:

- Thermal performance of focusing optics
- Available laser power too low

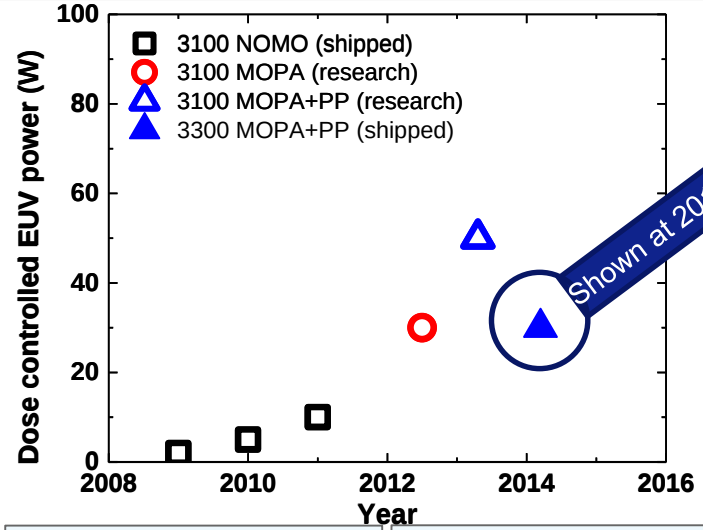


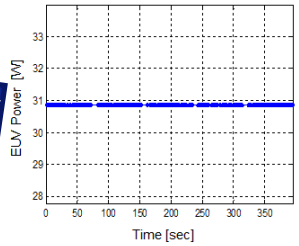
EUV source progress

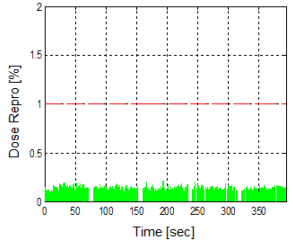
NXE:3300B MOPA Pre-pulse Principle: increased laser gain and improved focusing optics enable high EUV

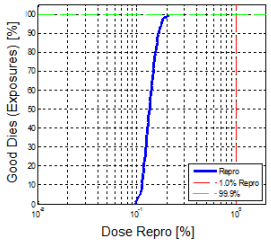
Industrialization: 30W EUV power on a production source

NXE:3300B MOPA+PP source operated in automated mode



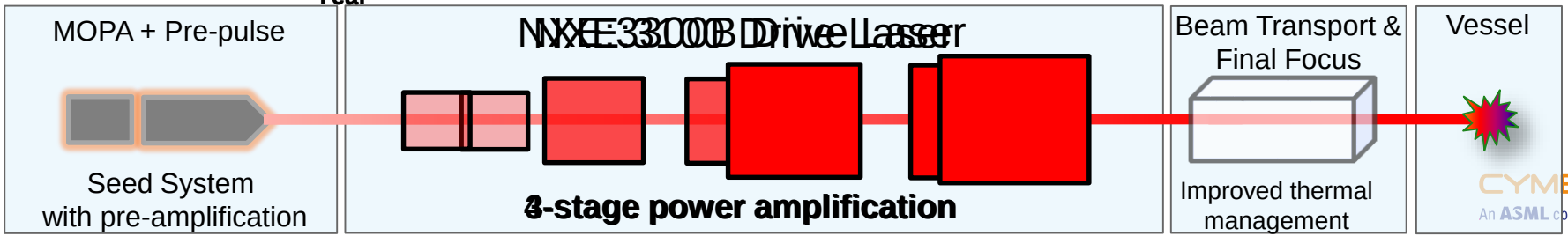






Early 2014 EUV power scaling limited by:

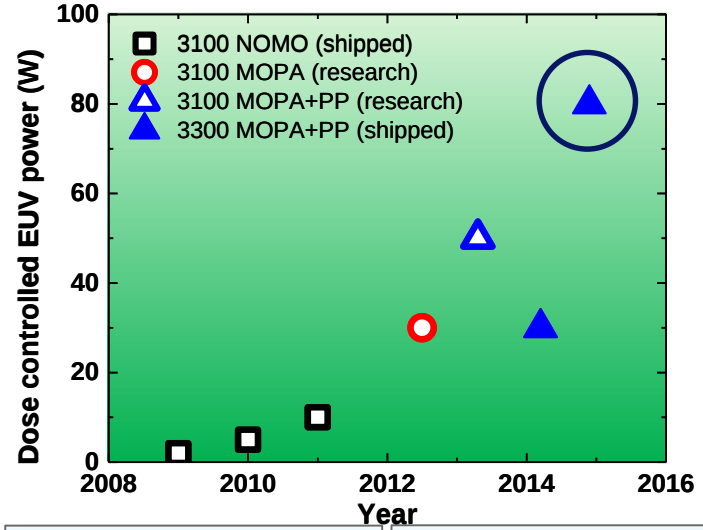
- Low CE from problems with laser pulse shaping that resulted in excessive “pedestal” energy
- Pedestal containment: reduce laser gain

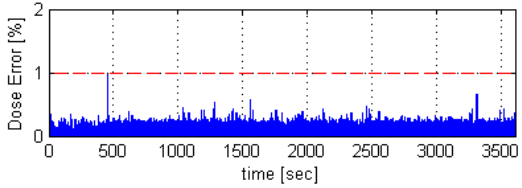


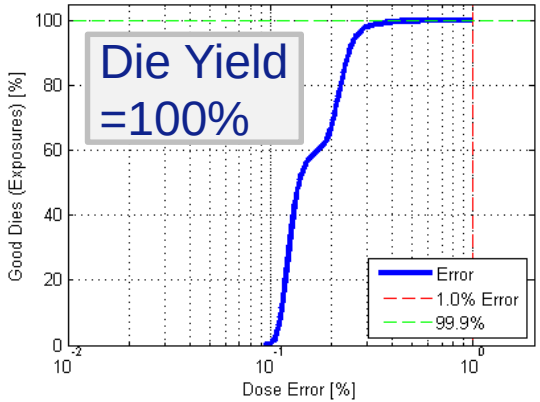
Historical perspective on EUV source progress

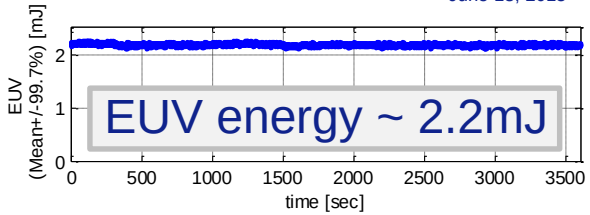
Progress during 2014: From 30W to 80W via improved pedestal extinction

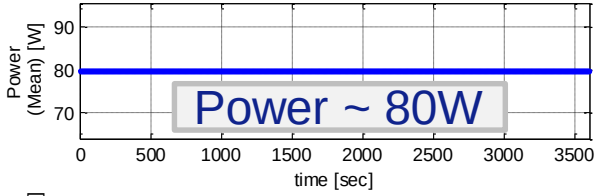
Data collected on Cymer 1, stand alone test source in San Diego, NXE:3300B

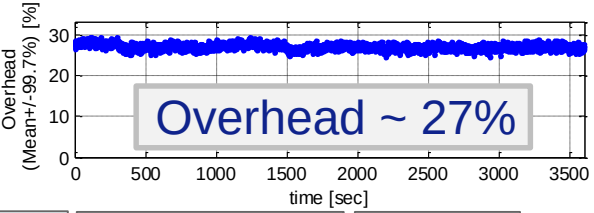


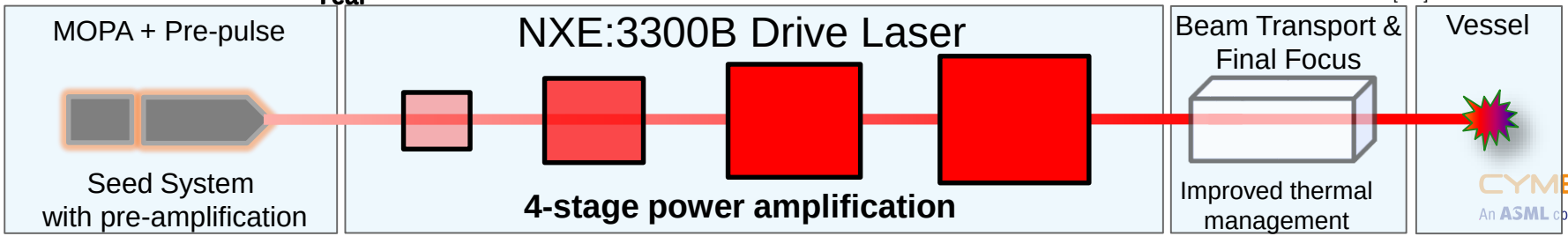








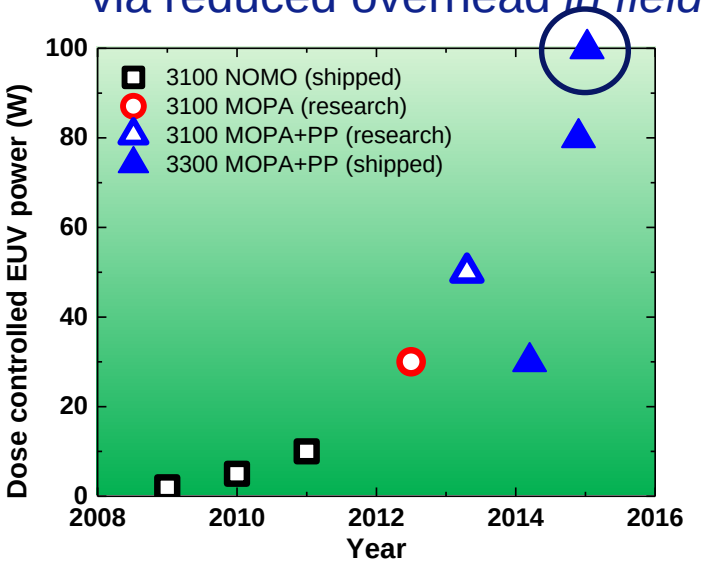


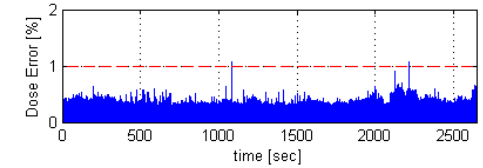


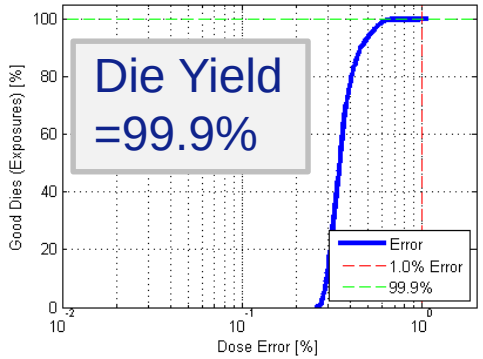
Historical perspective on EUV source progress

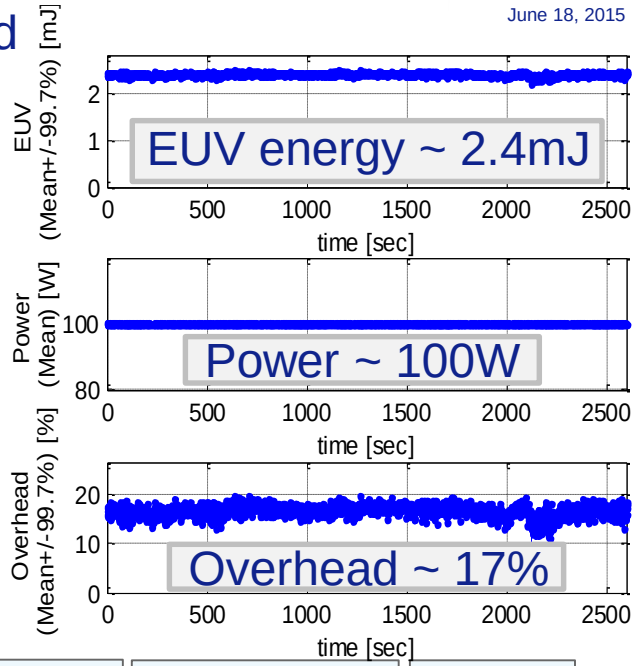
Progress during 2014: From 30W to 80W via improved pedestal extinction

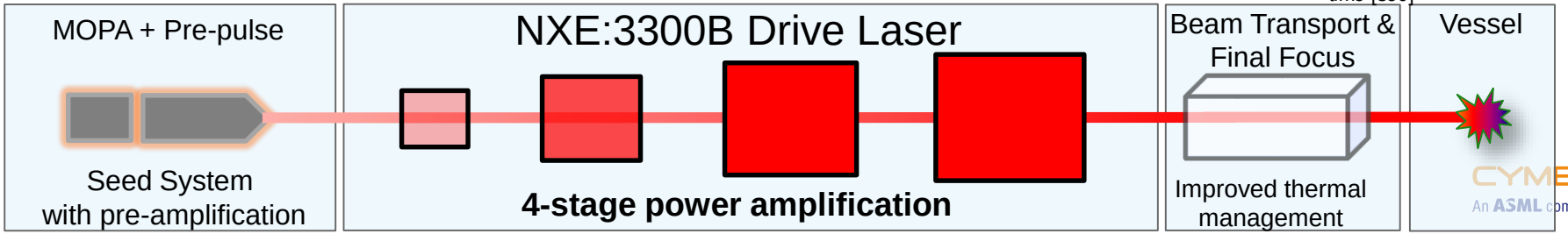
Progress during 2014: 100+W in-spec demonstrated via reduced overhead *in field and in house systems*











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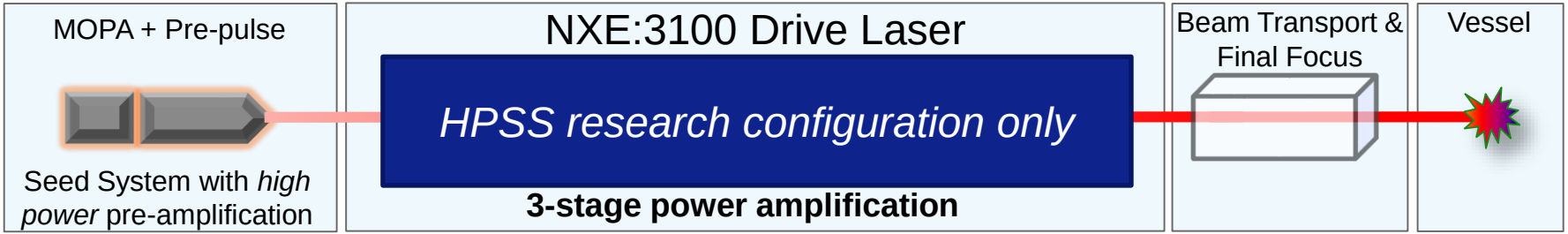
EUV power scaling beyond 100W

Next Generation Architecture Developments

Two architectural improvements to the laser are under development:

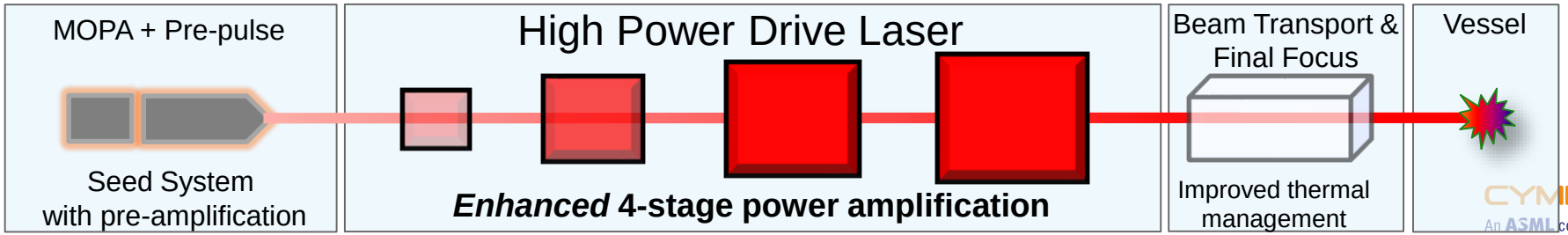
- **The high power seed system**

  Improved pulse shaping and greater pre-amplification



- **The high power drive laser**

  Greater power amplification capabilities



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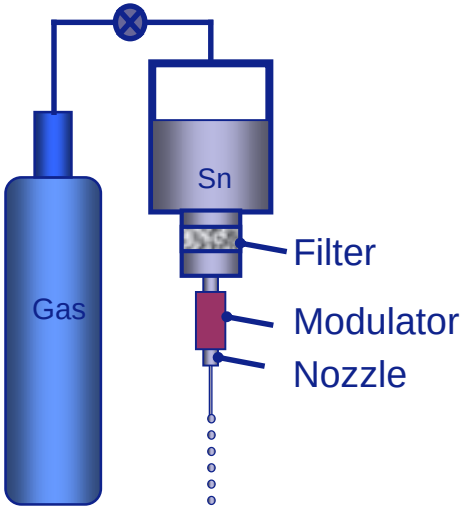
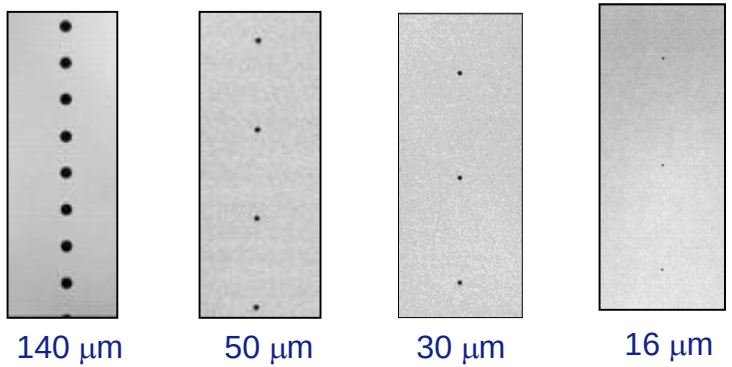
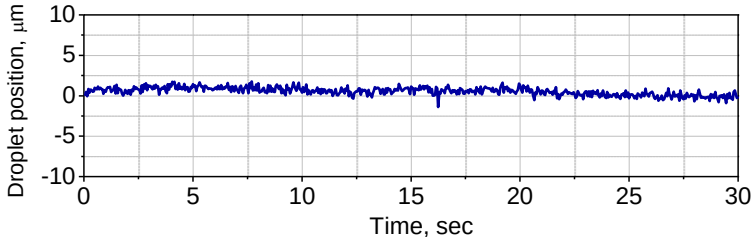
Droplet Generator

Droplet Generator, Principle of Operation

- Tin is loaded in a vessel & heated above melting point
- Pressure applied by an inert gas
- Tin flows through a filter prior to the nozzle
- Tin jet is modulated by mechanical vibrations

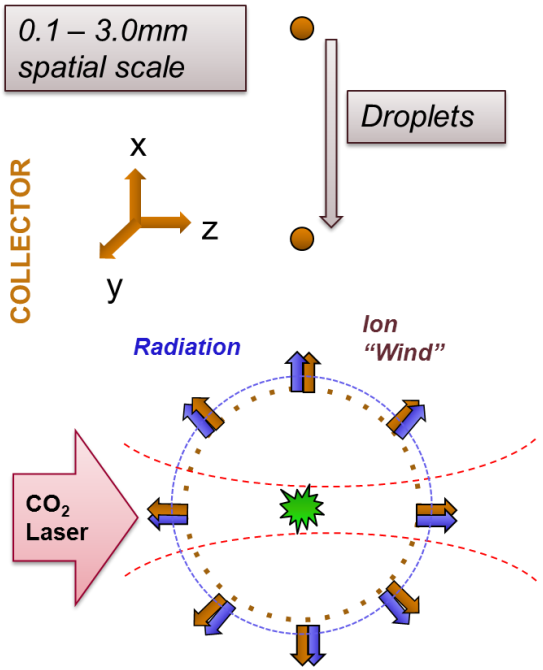






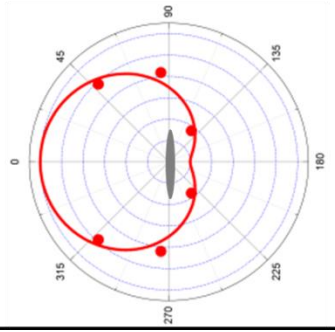
Short term droplet position stability σ~1μm

Forces on Droplets during EUV Generation



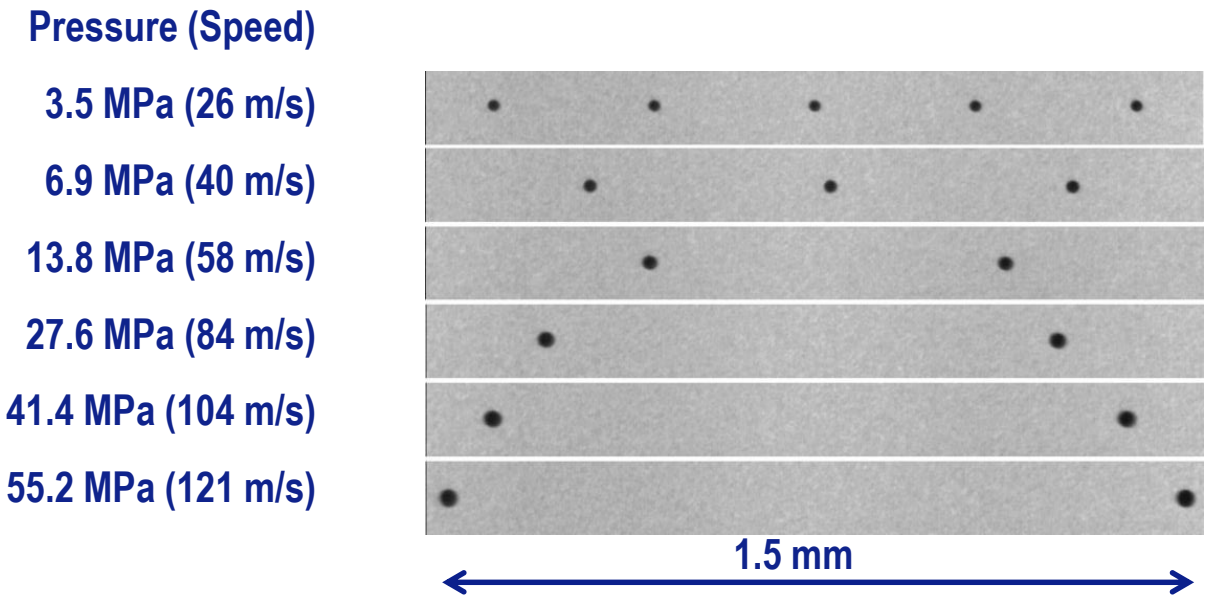
Measured Angular dependence of Forces on the droplets

Function fit: Force ~ EUVen *A*(1+cosθ+B) / R^2



High EUV power at high repetition rates drives requirements for higher speed droplets with large space between droplets

High Speed Droplet Generation



Tin droplets at 80 kHz and at different applied pressures.
Images taken at a distance of 200 mm from the nozzle

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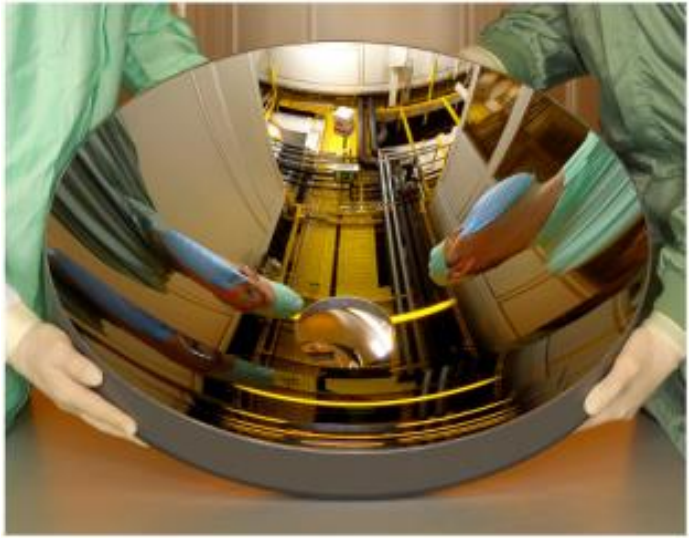
Collector Lifetime

EUV Collector: Normal Incidence

- Ellipsoidal design
  - Plasma at first focus
  - Power delivered to exposure tool at second focus (intermediate focus)
- 650 mm diameter
- Collection solid angle: 5 sr
- Average reflectivity: > 40%
- Wavelength matching across the entire collection area

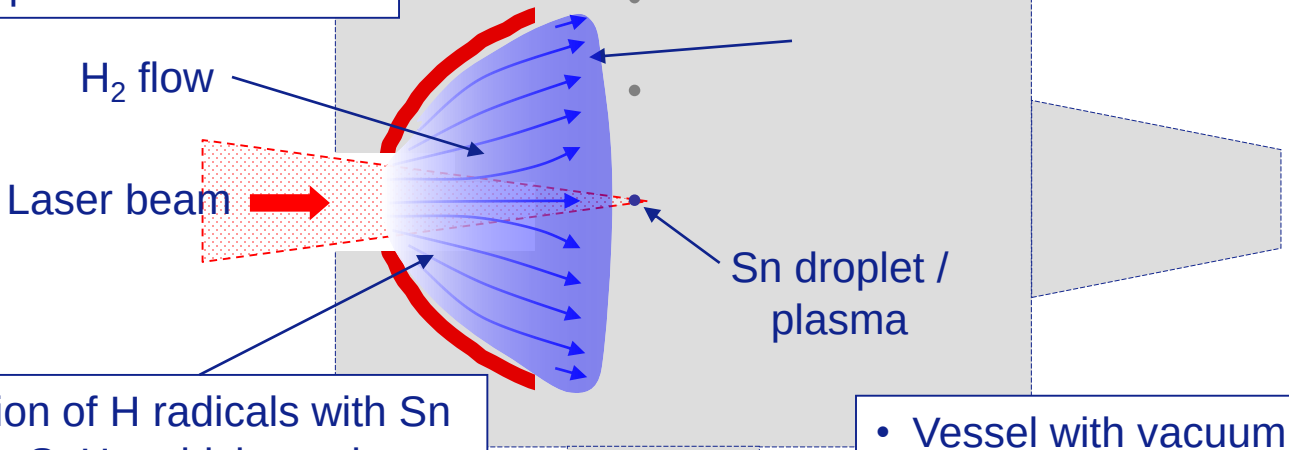


5sr Normal Incidence Graded Multilayer Coated Collector

Collector Protection

- Hydrogen buffer gas causes deceleration of ions
- Hydrogen flow away from collector reduces atomic tin deposition rate

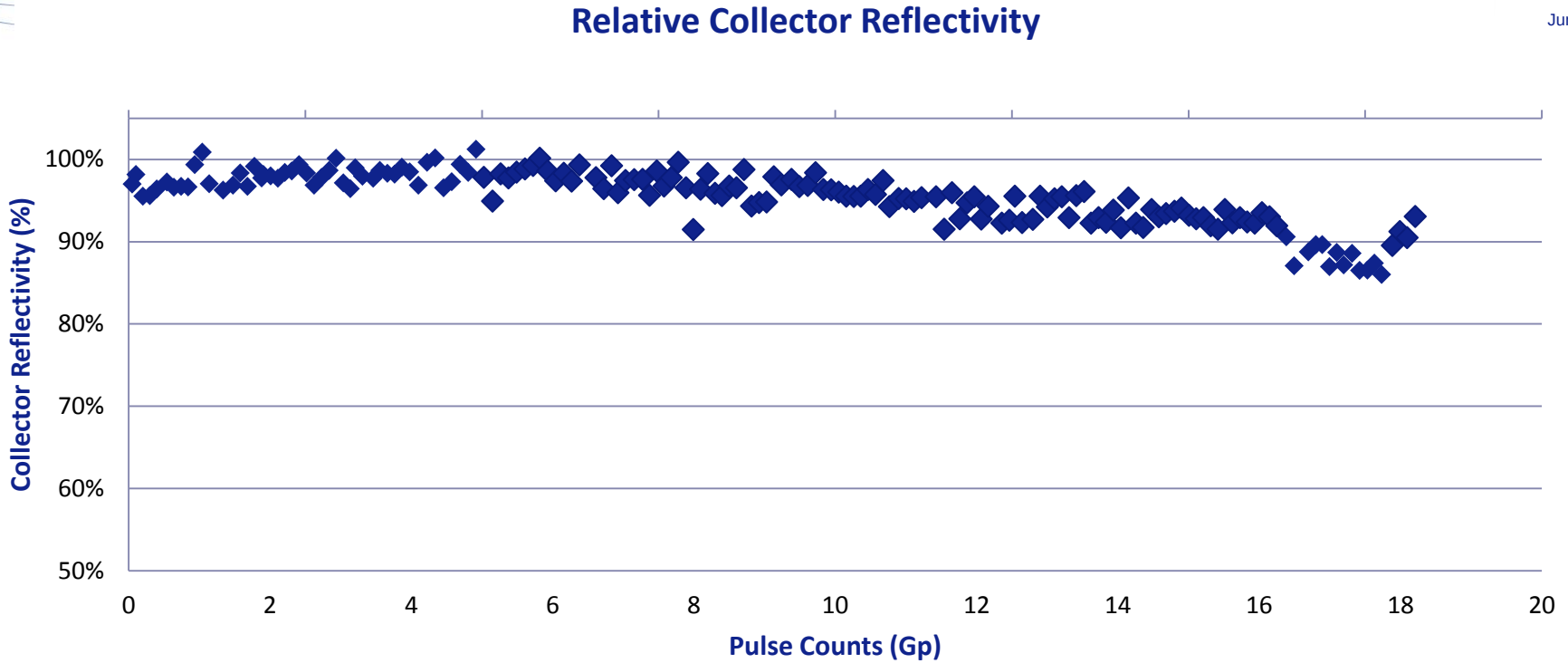
EUV collector
Temperature controlled



Reaction of H radicals with Sn to form SnH_4, which can be pumped away.
$Sn\ (s) + 4H\ (g) \rightarrow SnH_4\ (g)$

- Vessel with vacuum pumping to remove hot gas and tin vapor
- Internal hardware to collect micro particles

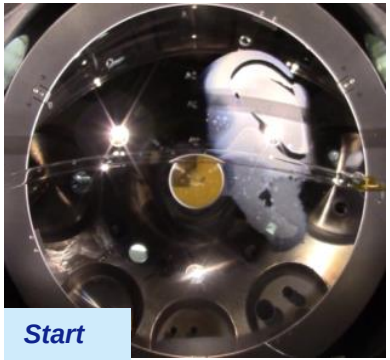
NXE 3300 Source Operation at 80W

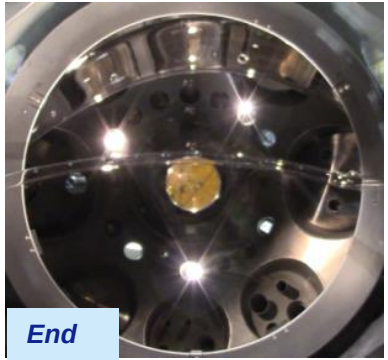


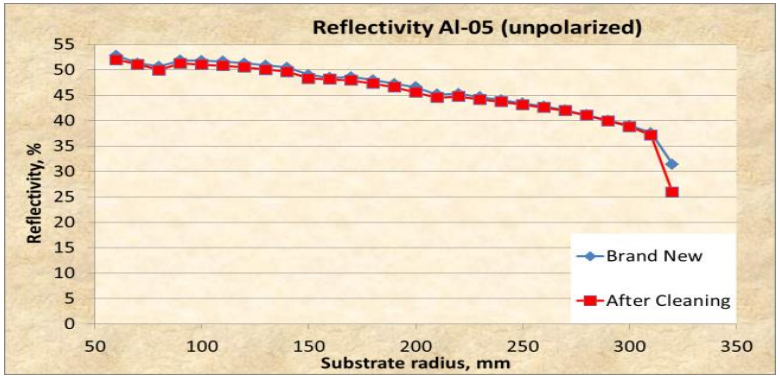
- ~ 0.5% reflectivity loss per Gigapulse
- Enables collector lifetime ~ 0.1 Terapulse at 80W

In-situ collector cleaning

Effectiveness of product configuration confirmed



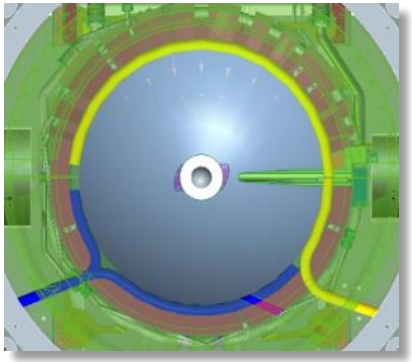




Reflectivity restored within 0.8% of original

Cleaning in off-line MOPA Prepulse development vessel

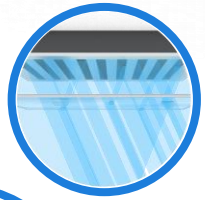
Field collector cleaned in NXE:3300 source vessel test rig

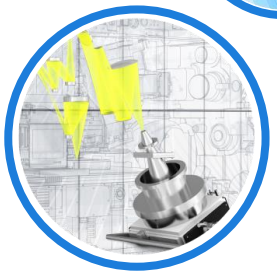


Off-line cleaning using NXE:3300B source vessel with product configuration hardware

NXE 3300 In-situ Collector Cleaning

Summary: EUV towards production insertion





At customers

- 8 NXE:3300B systems shipped, 7 exposing customer wafers
  - Stable 40W performance, 80W configuration being transferred to customers
    - More than 1000 wafers per day demonstrated during endurance test on one NXE:3300B

At ASML

- 4th generation NXE system (NXE:3350B) integration ongoing
- EUV cleanroom extension is under construction
- NXE:3300B initial imaging performance is in line with requirements for logic 7nm, DRAM 15nm
- 250W source architecture definition completed

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